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Design of a period batch control planning system for cellular manufacturing

Riezebos, J.

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Chapter 3 Period Batch Control

This chapter describes the Period Batch Control (PBC) system, a production planning system that has strongly been advocated for application within cellular manufacturing. It is said to be a simple and effective instrument in obtaining the benefits of group technology.

Firstly, Section § 3.1 presents the principles of PBC. Section § 3.2 considers the suitability of PBC for planning a cellular organized production system. Section § 3.3 shows the historical development of PBC, pays attention to various configurations of PBC that appeared in literature, and discusses contributions of literature on differences between PBC and other planning principles, such as Material Requirements Planning (MRP), Optimized Production Technology (OPT), and Kanban. Finally, Section § 3.4 presents an outline of our research on PBC system design.

This chapter answers the second research question:

*What are the main factors
that distinguish the basic unicycle Period Batch Control system
from other planning concepts in supporting the co-ordination requirements
in a multi-stage cellular manufacturing system?*

and it further introduces the design problem of Period Batch Control systems, which is treated in the remaining Chapters Four to Eight of this dissertation.

§ 3.1 Principles of Period Batch Control

Period Batch Control is a cyclical planning system that co-ordinates the various stages of transformation that are required in order to fulfil the demand of the customers. Effective co-ordination of the supply chain should make it possible to avoid or reduce decoupling stocks or other types of inefficiencies between successive transformation processes.

PBC differs from other planning systems in the way it accomplishes this co-ordination, and more specifically, in the three principles it applies in configuring the planning system:

- 1 **Single cycle ordering** refers to the *frequency* of releasing work orders:
each part has the same ordering frequency as its parent product
- 2 **Single phase** refers to the *release moment* of work orders:
work orders are released to the production system at the same moment (defined as the *start* of a period)
- 3 **Single offset time** refers to the *lead time* of work orders (per stage):
all work orders have identical lead times

The combination of principles 2 and 3 leads to work orders in the production system having all both identical release dates and identical due dates. The time available for completion of a work order, the offset time, is equal to the period length P or a multiple of P . The length of P is therefore an important design parameter of the PBC system.

We may still face the situation that the cycle length of products vary, even if we apply both principle 2 and 3. We define the *unicycle PBC system* (a term introduced by New, 1977) as a PBC system that uses the same cycle and same phase for all products and parts. Figure 3.1a shows such a system. All products A, B, C, and D use different order sizes. If an order is produced, the inventory curve starts to increase. If no production occurs, inventory decreases. A cycle is depicted as a shaded area, i.e. it is the time between two deliveries. All products do also use the same phase, as they start producing at the same moment in time.

In a unicycle PBC system it is still possible, although not very useful, to apply a cycle length for release of work orders to the system that differs from the offset time. This may be the case if the offset time is either greater or smaller than the cycle time. Figure 3.1a illustrates the situation of an offset time of one month and a cycle time of two months. The offset time is for each product only one month, as work orders are finished and the inventory curve starts decreasing after this month. Figure 3.1b shows an alternative with cycle times equal to the offset time. We will examine the latter system in detail and define it as follows:

The basic unicycle PBC system is a unicycle PBC system with a cycle time equal to the offset time. A unicycle PBC system uses the same cycle and same phase for all products and parts.

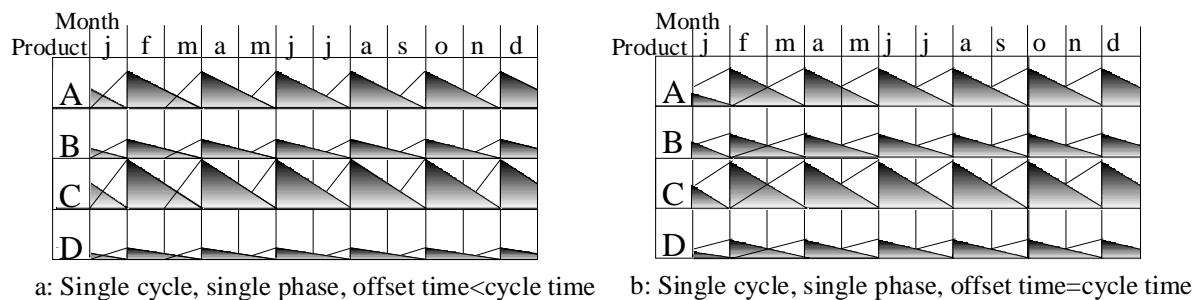


Figure 3.1 Unicycle (a) and Basic Unicycle (b) PBC system (compare Figure 3.11)

In order to obtain the required amount of an end product, often several transformation processes are involved in sequence. Subsets of work orders for these processes may be combined into a stage, which means that these work orders will be produced during the same period of time (*when*). A reason for such a subset may be that these orders are performed within one cell (*where*), or that input material is too costly. PBC releases work orders per stage, so a network of work orders has to be completed involving several periods of time.

We define N as the number of successive stages that are co-ordinated using PBC.

In a PBC system, the total throughput time T is determined by the product of the period length P and the number of stages N that have to be visited. If all products require processing according to this sequence of stages, they all have identical throughput time $T=P \cdot N$. Figure 3.2 shows the basic scheme of a PBC system with four stages.

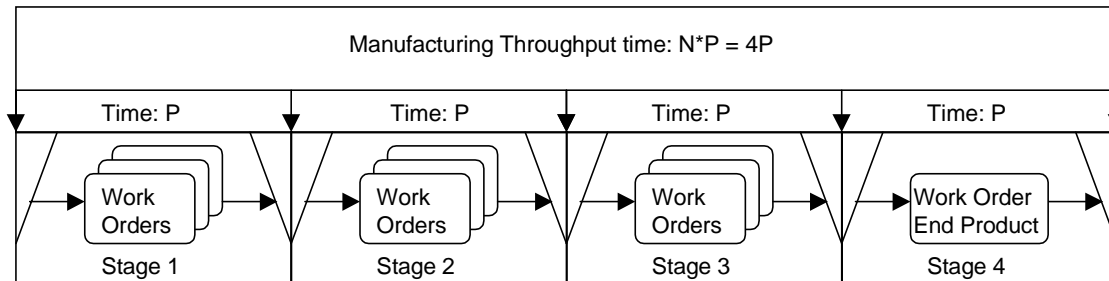


Figure 3.2 Basic PBC scheme

§ 3.1.1 Basic Unicycle PBC is a Single Cycle system

PBC is a single cycle system. It uses the same planning cycle for all products that are controlled with this system and each period it releases the work orders for all required parts and components for the amount of end product required in the next cycle. This periodicity is an essential feature of the PBC planning system, as it leads to the same frequency of occurrence of products in the plan, unless these products have lumpy demand.

Burbidge (1996) distinguishes between single cycle systems *at programming level* and *at ordering level*. Single cycle systems *at programming level* use the same planning cycle for all products that are controlled with the system. Each period, orders for these products can be released. If products can be ordered each period, this reduces either the customer order lead time or the average finished product inventory. Multi cycle systems *at programming level* apply different ordering frequencies for the products that are made.

Single cycle systems *at ordering level* translate the released orders for end products to *balanced sets* of orders for parts and components, by using lot for lot explosion. Work orders for parts are in this case also once per period released to the system. The main advantage of balanced ordering is the direct relationship between production requirements and end product requirements one or more periods ahead. This reduces the amount of work in progress and manufacturing throughput time. Additionally, it results in clear objectives for the production system, as they have to make what is actually needed in the next stage. Multi cycle systems *at ordering level* might either allow multiple release moments per period (for example, several containers in a Kanban system) or apply batching with order quantities larger than the amount required during one period, for example multiples of economic order quantities.

Burbidge (1990) argues against the use of both types of multi cycle systems, as they result in variations in the loading of the system over time, the *surge effect*. We illustrate this effect for a multi cycle system at programming level in Figure 3.3.

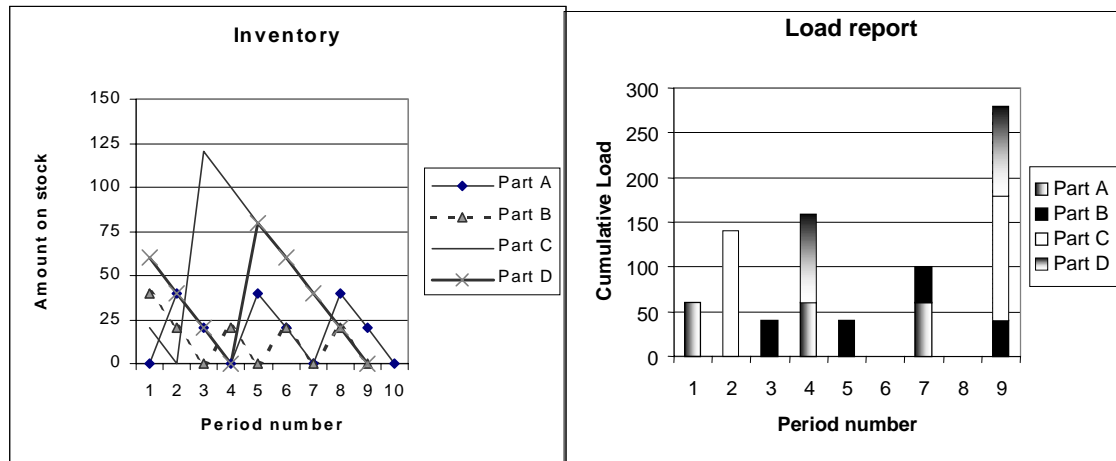


Figure 3.3 Surge effect: load fluctuations due to unequal planning frequencies

All four parts in this figure have different planning frequencies but an equal demand rate. The amount of inventory of these parts over time is presented in the left hand side of the figure, assuming a constant continuous demand. Production of a new batch of a part takes place during an offset time of one period. The resulting load on the system is shown in the right hand side figure. It shows that in some periods multiple batches are produced, while in other periods (6, 8) no batches at all have to be produced. This fluctuation is called the surge effect.

The arguments of Burbidge (e.g., 1990, 1993) against multi cycle systems are not valid for all types of multi cycle systems. In Chapter Five, we will discuss the use of (powered) nested order frequencies, both for parts and for products. With such order frequencies, the phasing of the various parts can be arranged such that the resulting load fluctuations do not exaggerate the fluctuations that are caused by demand variations.

Burbidge incorrectly assumes that all types of multi cycle systems apply both independent stock control and independent lot-size determination¹. However, multi cycle systems are not equivalent with independent decisions in the supply chain, but with different decisions with respect to parts or products.

Unicycle Period Batch Control is single cycle both at programming and at ordering level.

¹ As the terminology of Burbidge with respect to multi cycle and multi phase is not consistent, his arguments against multi cycle systems are sometimes confusing. In some cases, these arguments may remain valid if we read multi offset time or multi phase systems. See e.g., Burbidge (1989a), where he argues that multi cycle systems generate balance of load records (capacity profiles) that do not show if there is sufficient capacity. This conclusion holds for multi offset time, but not for multi cycle systems.

§ 3.1.2 Basic Unicycle PBC is a Single Phase system

PBC releases work orders in a single phase. At the release moment, all work orders have to be made available to the next stage. Multi phase systems allow different moments for release of subsets of work orders. A single phase system introduces a synchronization moment for the system, which is comparable to the transfer moment in an *intermittent serial line system* (see Scholl (1995)). We will elaborate on this analogy with serial line systems. Intermittent serial line systems with one or more workers per station are applied for many reasons of efficiency:

The first reason is that they provide clear but realistic objectives. All workers in such systems know at what time the system will require that their work has finished. If some stations are not able to complete their work package within this time, other workers that have finished their work might offer some help or else make it easier for these stations to accomplish their task within the available time².

The second efficiency related reason for applying serial line systems is that workers do not have to worry about the availability of required materials and tools. The transportation system organizes the transfer of work between stations, so there is no need to build up an input buffer before the work station. Availability of materials, components, and tools are guaranteed by other parts of the production system, which are responsible and specialized in these supply activities. Often, a logical decoupling from supply and usage of these materials is found, which reduces search time and accommodates an appropriate division in responsibilities. Otherwise, search time would become a significant part of the total station throughput time.

The synchronization in PBC due to the single phase principle is directed towards obtaining both types of benefits. Hence, the design of a PBC system should accommodate the determination of realistic objectives and a corresponding decomposition of the system.

The single phase principle of PBC causes a *less nervous* situation at the floor, as the set of work orders for this part of the production system is released at once. *Stability* during a period is achieved. This also means that in principal there will be *no disturbances* due to unexpected arrival of customer orders during the period. Pure single phase systems do not allow rush orders that arrive during the period. The inflexibility can partly be nullified by using small spare parts inventories. Rush orders for spare parts are then supplied from stock and the demand is replenished during the next period.

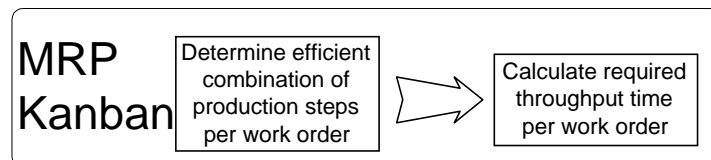
² The system of synchronous transfer in serial systems works in general only if it is possible to finish the work before the transfer moment, so the objectives have to be realistic. It prohibits that workers increase their independence from other contributors in the system. Such independence might work counterproductive, as it leads to more buffer inventory or decoupling inventory in the system in order to avoid blocking or starving, less awareness of problems in other parts of the system, and less incentives for improving the whole system instead of searching for local improvements.

If we compare single phase systems with multi phase systems, we see that the latter result in less overview of the complete amount of work that has to be performed within a period. This reduces the possibility to find a best way of working. If part of the work package arrives early in the period, and another part half way the period, then the planning of a resource that is required by both work packages is more difficult, as relevant information still has to arrive, while other related decisions (such as set-ups) already are being executed.

However, from this comparison we cannot draw the conclusion that single phase systems should be preferred to multi phase systems. Recent developments in the field of continuous work order release systems (see e.g., Land and Gaalman, 1998, van de Wakker, 1993) show that information on the actual progress of work at the shop floor can effectively be used for improving the release decision. Therefore, the advantages of single phase systems need not be prevailing in each production situation.

§ 3.1.3 Basic Unicycle PBC is a Single Offset time system

PBC is called a single offset time system, a term introduced by Steele (1998). PBC uses the same internal throughput time (offset time) for work orders that are released to a stage. This results in the same manufacturing throughput time T for all products that require an identical number of stages. As a consequence, the definition of these work orders becomes very important. Traditionally, these definitions can be deduced from the levels in the Bill Of Materials (BOM)³, but the throughput time that is needed for such a level transition is determined separately. Both decisions (work order definition and work order throughput time determination) are managerial decisions with a strong impact on production planning.



Decomposition of product structure in work orders

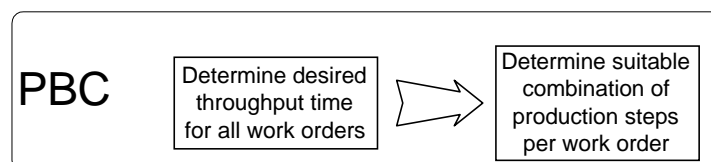


Figure 3.4 Work order definition in MRP and PBC

³ Bill Of Materials A listing of all the subassemblies, parts, and raw materials that go into a parent assembly showing the quantity of each required to make an assembly, Apics (1980)

Within MRP and Kanban systems, the number of operations that are combined into one work order (production Kanban) depends mainly on the organization of the production facilities and the possibility of obtaining efficiencies from batching. If an efficient combination has been determined, the planned throughput time or Kanban lead time for this set of operations is being fixed. This makes the managerial decision about the length of the planned throughput time a consequence of the implicit managerial decision about the desired combination of operations in one work order. In general this leads to multi offset time systems, as the required throughput time per work order may differ for the various combinations of operations that are distinguished.

PBC systems start at the opposite side, as shown in Figure 3.4. The managerial decision about the desired length of the planned throughput time per work order precedes the managerial decision about the combination of operations into a work order. The throughput time decision has to be equal for all work orders in a single offset time system. That decision can therefore constrain the definition of work orders, as each work order within a stage has to be finished at the end of the offset time. So it affects the speed, dependability, and flexibility of the system.

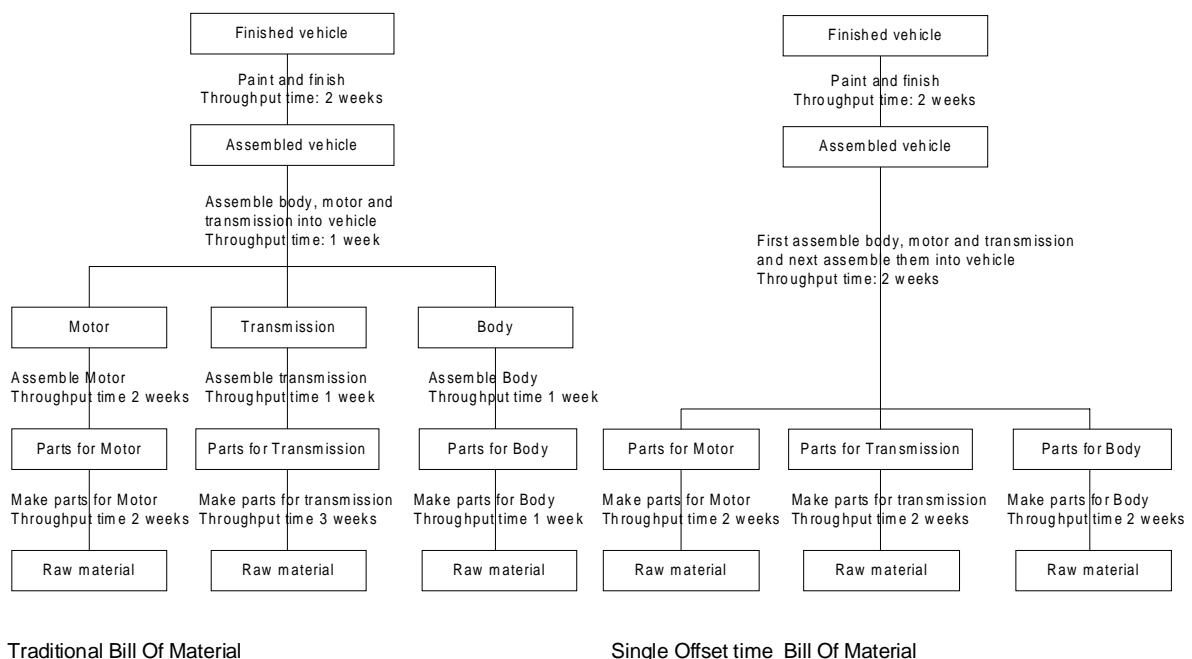


Figure 3.5 Example of traditional versus single offset time Bill of Material

We constructed an example in Figure 3.5 that shows the different BOM structure due to the single offset time principle. The left hand figure shows a traditional BOM structure with varying throughput time per work order (level transition), but relatively simple content of work orders. Within the production organization, it will be easy to address these work orders to specific parts of the system. For example, the work order for motor assembly can be found within the department that assembles motors. Planned throughput time is rounded up to an integral number of weeks. Expected throughput time will be less than this number of weeks.

The example of the single offset time BOM at the right side in Figure 3.5 shows an offset time of two weeks. Operations that can be combined into one work order and can be expected to finish within this offset time are combined into one work order. We see that this has led to the elimination of one level in the BOM. The assembly of Motor, Transmission and Body into an assembled product took less than one week, and could be combined with the assembly of the individual components without exceeding the throughput time of two weeks. The same holds for the production of parts for transmission, which now takes only two weeks. This may require a different priority system with respect to the allocation of resources to the work orders, as the critical capacity for producing parts for the transmission is also used by the less critical production of parts for the body. This set of measures reduces the total cumulative throughput time with one week.

The single offset time principle leads to a re-consideration of BOM structuring in planning system design. Browne et al. [1988: 264] note that '*the BOM concept may have had too much influence on the design of shop floor routings*'. PBC provides an alternative.

§ 3.1.4 Variants of PBC in practice

The basic unicycle period batch control system is single phase, single offset time, and single cycle, both at programming and at ordering level. Many of the systems that are known to operate as a PBC system are variants of this specific system. This holds true both for systems that are actually operating in practice and for systems that are described in literature. The systems that operate in practice are not so rigid as may be expected from the system description. This also makes it quite difficult to compare the effectiveness of differences in system design.

In the Netherlands, we are aware of a number of firms that have considered and applied PBC systems. Studies on the design of the planning system have been performed at Marko B.V., Veendam, manufacturer of school furniture, at the clean room assembly department of a Philips machining plant in Acht, at the parts manufacturing division of Delft Instruments, and at El-O-Matic component fabrication plant. In Chapter Four of his dissertation, Slomp (1993) describes some aspects of a PBC system in combination with a flexible manufacturing system at El-O-Matic. He proposed to use a multi offset time system. The studies showed that the specific circumstances and possibilities in managing disturbances influenced the design of the planning system and made it less rigid than could be expected from the initial system design.

Burbidge (1996) describes a number of cases where PBC systems have been implemented. He distinguishes between implosive, process, explosive, and jobbing industry applications.

In implosive industries, many product and packaging variants have to be delivered, making it uneconomical to produce on stock. The use of PBC facilitated both short delivery times and economic sequencing within a period in order to reduce the total set-up time needed. Variants

can be found with respect to the single cycle at programming level principle. The single phase principle allowed the development of specific sequences, as all orders that had to be produced within the period were known in advance.

Applications of PBC in food processing industry showed the same pattern, but here the PBC systems operated with one day periods, and shorter period lengths of half a day or one shift were also possible, if required by the short shelf life of the products. The short periods were still preferred over continuous production, because of the possibilities to change the sequence of processing work orders between stages, enabling the system to find sequences that efficiently used the various facilities, such as ovens, freezers, and other equipment that led to sequence dependent set-up times.

Most PBC systems that are described regard explosive industries with both assembly and component production. The PBC systems for these situations had to face long throughput times. The PBC systems that were developed for these cases are all specific variants of the basic unicycle PBC, as company specific solutions were developed that made it possible to shorten the total throughput time and improve the co-ordination of subsequent stages. The systems were mainly single cycle at ordering level, but variants with respect to the single phase, single offset time, and single cycle at programming level principles were developed.

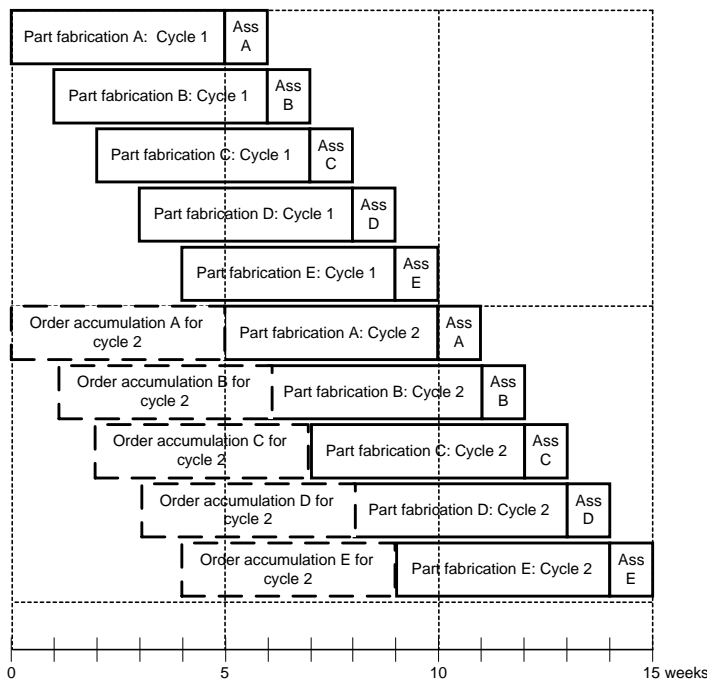


Figure 3.6 Kumera Oy Cyclical planning system

Other PBC systems found in literature are from Whybark, 1984, Borgen, 1996, and Melby, 1994. Whybark (1984) describes a single cycle, multi phase, multi offset time system. He reported on a cyclical planning system for the Finnish Kumera Oy. Details on his system are described in Figure 3.6. The cycle time of the system is five weeks. The offset time in parts

production is equal to this cycle time (five weeks), but in assembly, work orders have an offset time of one week. The system is not single phase, as work orders for different part types are released in separate weeks. The total throughput time of an order consists of six weeks manufacturing lead time and maximum five weeks pre-release waiting time. Whybark found an increase in inventory turnover from 2.5 to more than 10 times a year, and a delivery accuracy increase from 50% to 98% of orders less than 3 weeks late.

Borgen (1996) applies a PBC system for co-ordinating the production of newspapers. He focuses on the pre-press production stages and designs a single cycle, single phase, single offset time system with flexible allocation of capacity to the various stages. Main advantage of this PBC system is a synchronized transfer and fewer interrupts during a period.

Melby (1994) describes a period batch control system at Norsk Kongsberg Defense and Aerospace Maskinering/Montasje. The machining department and assembly operated with a four week cycle with weekly loading and a PBC system was developed for the planning within the production cells.

From this review, we conclude that the principles of PBC are not blindly applied when designing a PBC system for a practical situation. A trade-off should be made between the advantages of applying the principles and the costs of their application in these situations. Note however, that the design of a PBC system is not a one time exercise, as improving both the production and planning system are essential. The basic unicycle PBC system may therefore function as an ultimate goal for many of the PBC systems found in practice, comparable with the zero-inventories crusade that was propagated in Japan and in APICS literature of the 1980s.

§ 3.1.5 Operation of a PBC system

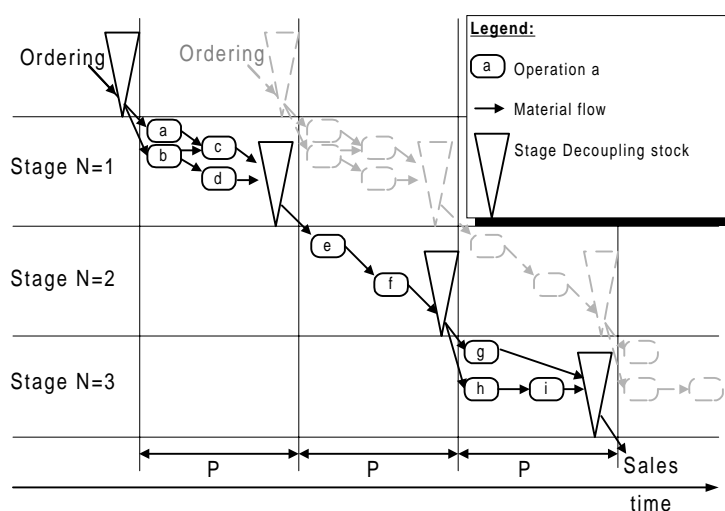


Figure 3.7 PBC system with 3 stages

The operation of a basic unicycle PBC system can be illustrated with Figure 3.7. Before production starts, the required raw materials have been ordered and received such that at the start of a new period they are made available to stage $N=1$. The operations in this stage are performed according to the specified work orders and have to be ready before the end of the period with length P . Parts and components can be put in a decoupling stock where they await transfer to the next stage. All work orders have to be finished before the start of the next period in order to effectively decouple both stages. At the start of the next period, the work orders for the next stage are given to the machine operators, who may start them at a free resource, and the required materials can be transferred as they are available in the exact amount needed in the decoupling stock position. At the same time, the operations in stage $N=1$ receive new work orders that again have to be completed within one period length P . As each stage in the production system has exactly one period of length P available to complete the required operations, the total manufacturing throughput time T equals the number of stages N times this period length P .

The length of the customer order lead time depends on the positioning of the Customer Order Decoupling Point, CODP, a term introduced by Hoekstra and Romme (1985). Assume for simplicity, that we do not hold anonymous inventories, i.e. we purchase to order. Then the customer order lead time will also consist of time for ordering raw materials, required parts, controlling designs and required tools, and so on. PBC allocates these activities in a preceding ordering period O . The products for which these activities are performed have entered the system during the order acceptance period AC . The delivery of the products to the customer is assumed to take place in a separate stage after production is finished: sales period S .

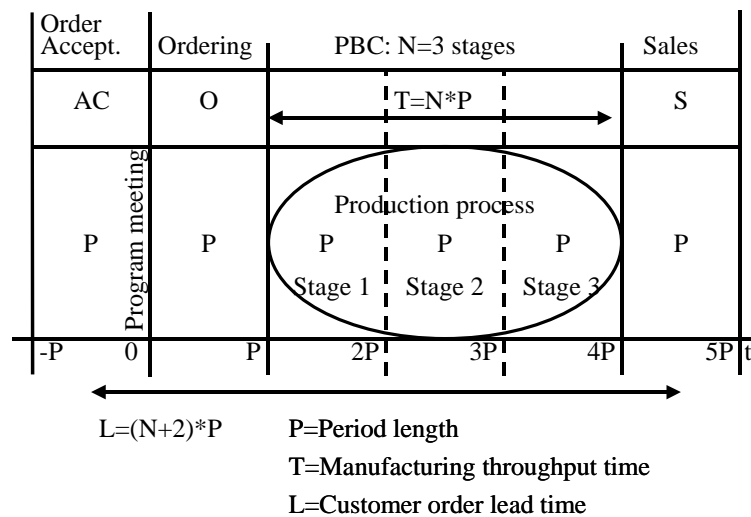


Figure 3.8 Customer order lead time L versus Throughput time T

The necessity of the stages O and S depends on the characteristics of the supply chain, i.e. the length of the delivery times of both the required parts and the end product. Most publications on PBC in complex manufacturing situations assume that separate ordering and sales phases are required, but in practice solutions may be found that can eliminate the necessity of these stages. Burbidge (1975a, 1993) describes several of these solutions.

The length of stages O and S need not be equal to the period length P^4 , but again for simplicity, we will assume that the total customer order lead time also includes an ordering and a sales stage, both with length P. We will therefore assume that the customer order throughput time in the sales stage is between 0 and P, so the mean throughput time in stage S will be $\frac{1}{2}P$. The minimal total customer order lead time is in that case equal to $(N+1\frac{1}{2})\cdot P$. However, if an order arrives at the system just after the work package has been released to the system, a waiting time occurs before the next decision moment on order acceptance. In a single cycle system at programming level like PBC, only once per period is such a decision about order acceptance and release taken. All orders that arrive in between have to await this decision before further action is undertaken. This waiting time will not exceed P, so the mean customer order lead time is $\frac{1}{2}P + (N+1\frac{1}{2})\cdot P$, as illustrated in Figure 3.8. The smallest possible customer order throughput time is $(N+1)\cdot P$, and the largest is $(1+N+2)\cdot P$.

If the customer order decoupling point is located later in the production or supply chain, the customer order throughput time decreases, but the total throughput time for the product might increase, because of a longer mean waiting time in the decoupling point. The specificity of the semi-finished products in the decoupling point increases, which results in less demand per stock item and, on average, longer waiting times before demand occurs. PBC can still be used for regulating the stages before and after the decoupling point, but the anonymous production to stock before the decoupling point may also be regulated by other ordering systems.

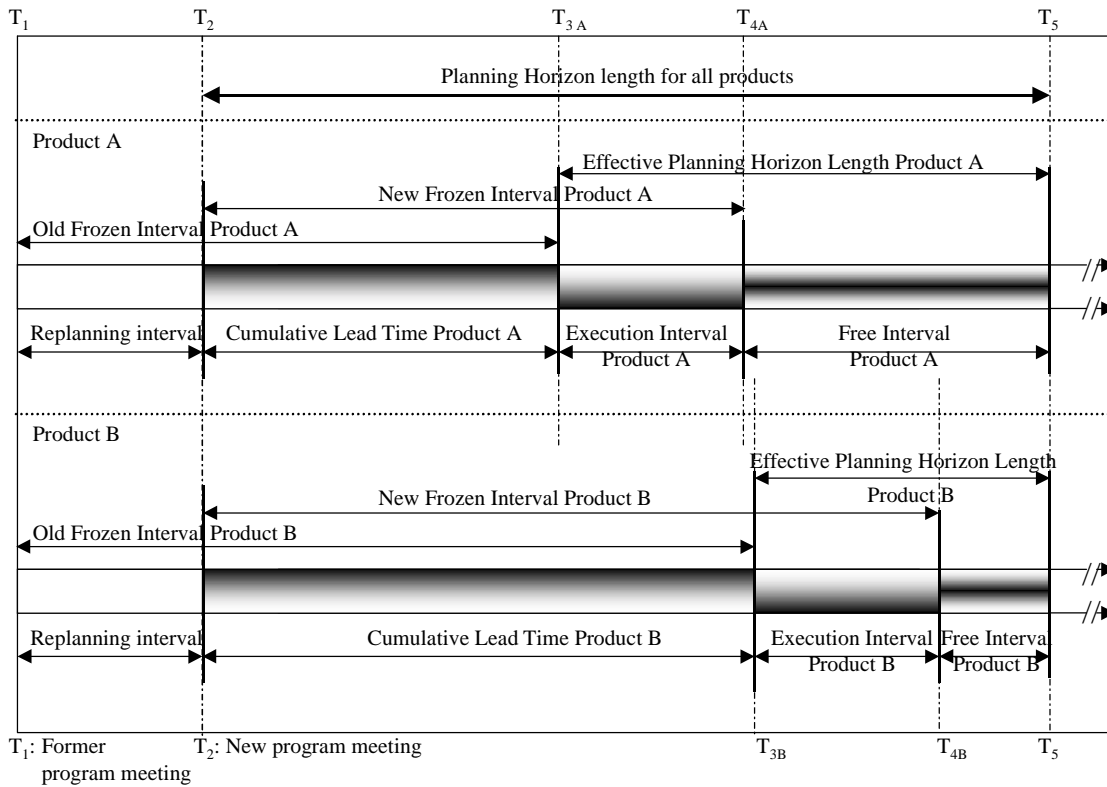
§ 3.1.6 Planning functions in program meetings

Figure 3.8 shows a program meeting at the end of the order acceptance stage. This program meeting decides which orders that have entered the system should be accepted. It determines if specific actions have to be taken (such as hiring extra capacity) in order to complete these orders within the total throughput time. Such actions can also be considered for orders that were already released in an earlier period; for example, because capacity in a later stage, e.g. the assembly department, is less than expected when the orders were released, due to illness of some employees in the assembly department.

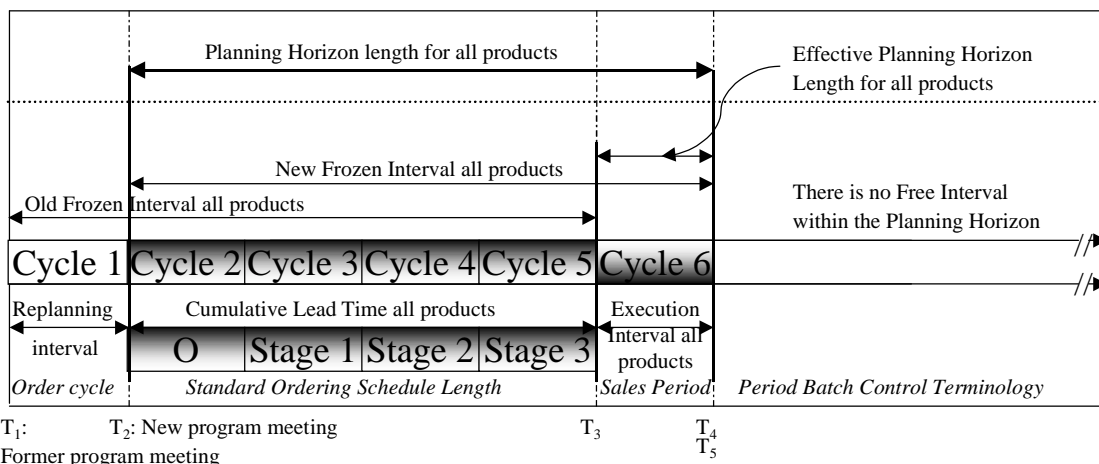
One result of a program meeting is a list of accepted orders that have to be released after an ordering stage O to the production system. They will be available to the customer after a manufacturing throughput time T plus the required amount of delivery time during the sales period. Other results of the program meeting include plans for the required changes in capacity in future periods, replenishment orders for spare parts, and so on.

⁴ The length of AC is equal to P, but the length of O and S need not be fixed at P. The latter is not seen by Burbidge (1996). He states that in many cases the length O (the call off period) determines the period length P. If the ordering period would take only $\frac{1}{2}P$, the release of work orders could take place half way a period, only once per period, in order to reduce the total customer order lead time.

In terms of MRP, the program meeting can be seen as the determination of the MPS master production schedule, based on a rough cut capacity check. Burbidge introduced the term *flexible programming* for the process of determining these short term production plans that are input for the ordering process of PBC. The planning horizon that is taken into account in this program is at least the length of the customer order lead time, but it may be necessary to take a longer horizon into account.



Master Production Schedule Effective Planning Horizon and Frozen Period with MRP



Effective Planning Horizon and Frozen Period with PBC (Purchase to order situation)

Figure 3.9 Master Production Scheduling versus PBC Flexible Programming

The difference between the PBC flexible programming approach and the MPS scheduling procedure is illustrated in Figure 3.9. The upper part of this figure shows the MPS for two products A and B, each having its own lead time. The lead time difference results in different execution periods: the future periods for which the master production scheduler has to determine the production program of these products. Even the length of these periods need not be the same in a standard MPS plan. This introduces conceptual difficulties for all people involved in the program determination.

The different timings of these execution periods also imply that the effective length of the planning horizon for these products differs. Requirement schedules of parts that are used in these final products also use this effective planning horizon. Discrete lot-sizing procedures, such as least unit cost, are sensitive for changes in the planning horizon length and may require longer planning horizons in order to become useful.

The lower part in Figure 3.9 shows the programming method of PBC. The usage of single cycle at ordering level leads to lot for lot scheduling. This implies that there is no need for a planning horizon that exceeds the execution interval. The length of the replanning period equals the execution interval. Each product has the same ordering schedule and period length. There is only one execution interval for which the final schedule is determined in the program meeting. The conceptual difficulties of scheduling for different periods in time are eliminated.

PBC terminology is somewhat different than used in other literature on planning systems (see e.g., Kanet, 1986, Sridharan & Berry, 1990, Yeung, Wong, & Ma, 1998). Figure 3.9 enables an easy comparability of the terminology used in these systems.

A program can be considered as the result of negotiations between sales, production, and other disciplines. The occurrence of strong fluctuations in the loading of the system may make it necessary to smooth production, to reallocate labour capacity, or to replenish spare parts inventory. Seasonal fluctuations may necessitate production of some products to stock. If sales requires a wide range of products with many design variants, different lead times, or different order promise times, the production program may not simply be made equal to the accumulation of sales orders that were received in the preceding period. In these cases, the standard MPS procedures apply, including the disadvantages that are inherent to them and that were discussed in Figure 3.9. The function of the program meeting within PBC changes accordingly from simply accumulating received orders and releasing work orders, as shown in Figure 3.10, to complex planning. This planning process trades off due date reliability in the short and long term and '*producability*'⁵ of the work package. To achieve producability, other objectives than short term due date reliability play a prevailing role in the planning process, resulting in PBC systems that no more operate as single cycle systems at programming level.

⁵ Producability denotes the possibility of realizing the various demands that are placed on the production system.

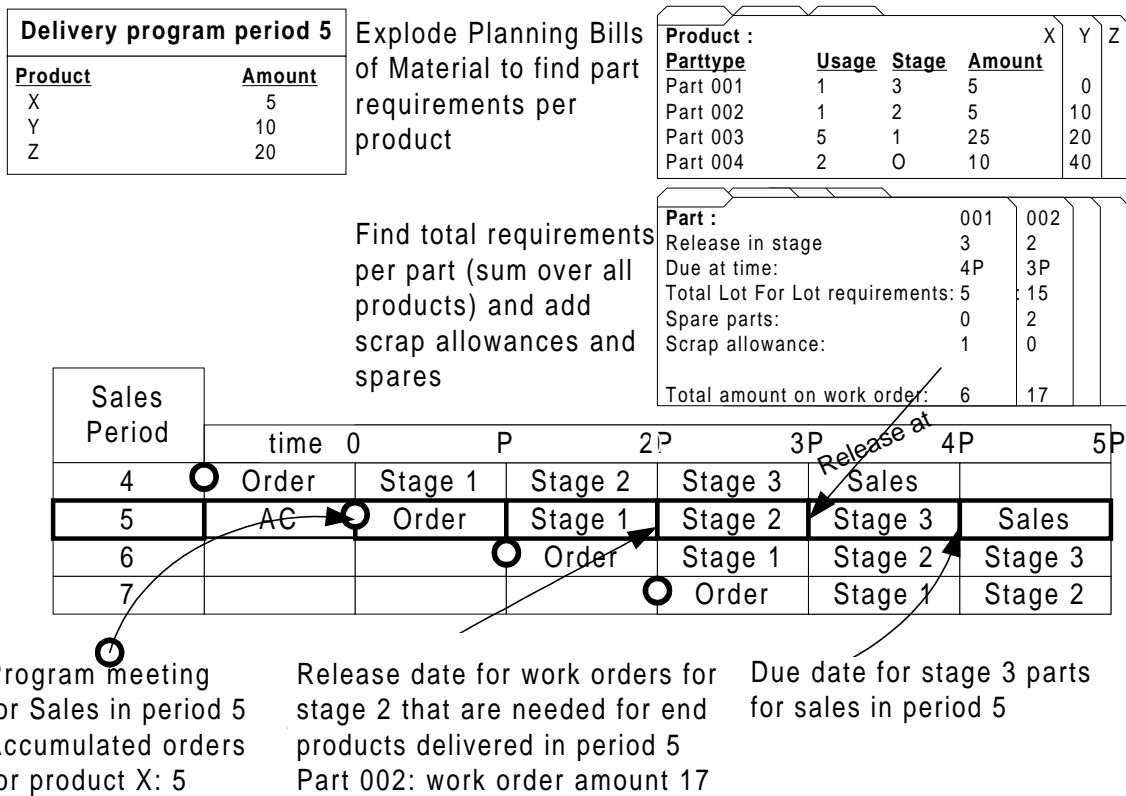


Figure 3.10 Operation of a PBC system (free to Burbidge [1975a: figure 4.2])

§ 3.2 Suitability of PBC for cellular manufacturing

Why should a system that uses the three principles *single cycle, single phase, and single offset time*, be suitable for cellular manufacturing? In general, we cannot say that PBC systems are suitable for all cellular manufacturing situations. Absolute claims on the applicability or suitability of production planning methods for a broad range of production situations will never be valid. However, some facets of cellular manufacturing may fit well with the three principles of a PBC system. We can find such facets in the typical co-ordination requirements of cellular manufacturing systems that have been determined in Chapter Two. Other facets can be found in three categories of typically desired benefits of cellular manufacturing systems: empowerment, learning capability, and delivery response (Olorunniwo & Udo, 1999). We will discuss the fit between the three principles and these facets.

Sequential co-ordination requirements

The three principles result in a time phased planning of the goods flow between successive transformation stages. Therefore, sequential co-ordination requirements between these stages are handled by the planning system. If the cellular manufacturing system requires adequate sequential co-ordination, either within or between cells, a PBC system can provide this through its stage decomposition, although it does so quite rigidly. Cellular systems that produce a complete product within one cell and do not require a formal co-ordination of the successive transformation steps may obtain better support from another planning system. It should be noted that the definition of stages is an important factor in the effectiveness of the sequential co-ordination that PBC provides. For example, stage definition allows enough flexibility to control the increase of working capital caused by expensive parts. Completing these products can be organised such that these parts are included as late as possible. Work orders for other products can be defined such that cells will be able to finish their total work package within a period.

Simultaneous co-ordination requirements

Simultaneous relationships exist if various elements in a system produce for the same end item demand. This demand is in PBC systems directly exploded (with minor corrections) into balanced sets of parts, without considering further batching possibilities. PBC does not consider other batching policies than lot for lot ordering. The time phased co-ordination mechanism allocates these work orders for parts to the various stages. This causes a direct relationship between actual production quantities for parts in a period and MPS demand in a specific future period, which enables the use of simultaneous relationships within the cellular manufacturing system. For example, the simultaneous co-ordination requirements that result if end product orders are cancelled while the production of parts already has started, are easier handled in case of such a direct relationship. The pegging procedure is less error sensitive.

Latent co-ordination requirements

The existence of shared resources and alternative routings in a cellular manufacturing system generates latent co-ordination requirements. The suitability of a PBC system for these co-ordination requirements depends on the specific situation.

- If operations on a shared resource are allocated to a separate stage for a number of products, the co-ordination of this shared resource can be performed through PBC. However, if a shared resource functions as a service centre with very short processing times (as described in Case V in Chapter Two), the above mentioned usage of PBC for the formal co-ordination of such a resource will probably not be appropriate, although this depends on the length of the period.
- Alternative routings can be used in PBC as far as these routings concern processes in one of the successive transformation stages. The work orders for these transformation stages will not be released to the system before the start of the next period or even later. This leaves the production planner enough time to prepare the routing change and deliver the required materials to another part of the system. Hence, information on the possibility of alternative routings may be used in determining the planning bill of materials for PBC.

The principles of single phase and single offset time enable the planning system to activate the possibilities of the system at the overall goods flow control planning without disturbing the actual progress at the floor. Multi offset time systems would make it necessary for the planning system to interfere with the detailed planning of the cell. Multi phase systems would make detailed planning within the cell less easy to accomplish. Therefore, the ability of the overall planning system to anticipate or react on changes with respect to the overall goods flow control diminishes, unless the detailed planning tasks become part of that system.

Empowerment

Cellular manufacturing systems expect many benefits from the changed position of the worker in the system. Empowering workers makes them more responsible for their actions and decisions. They have to receive the authority and autonomy to take these decisions, and receive the opportunity to obtain feedback on the results of their actions and decisions. The PBC system facilitates this mainly through the periodicity with which the system operates. This periodicity and synchronization of the goods flow within the transformation system leads to clear objectives, both for the system as a whole and for the various workers involved in the successive transformation stages. They know that all work that is received at the start of a period has to be finished at the end of the same period. In the mean time, no new orders will be released to their part of the system. PBC does not prescribe to them in what sequence the work orders have to be produced, if this is the responsibility of the cell workers. However, PBC restricts the authority of the cell workers through its stage decomposition. If successive operations also have to be performed within a cell but are allocated to a successive stage, cells are not allowed to proceed with these operations. The decision boundaries are clear and are not too frequently modified. Therefore, the PBC system enables a decomposition of the co-ordination that allows for the desired cell autonomy and supports empowerment.

Learning capability

Cellular manufacturing systems expect further benefits through the development of improved methods that focus on a rationalization and redesign of elements in the production system, see e.g. Gallagher and Knight (1986). Senge (1990) notes the development of such methods as a process of learning, which may be facilitated through stimuli from the environment. The three principles of PBC systems, stability, overview, and repetition, provide such stimuli, as they enable the work force to develop such improvements and find schedules that fit the various requirements of both their part of the system and the overall planning system. If almost the same mix of orders is repeated during successive periods, they may use this repeating pattern to develop specific solutions that make it possible to operate with a higher efficiency. For example, the quality of the schedules and the set-up and material handling efficiency may increase if specific attention is paid to the repeating pattern. The same holds true for the development of methods to reduce the amount of scrap and increase the yield accuracy of machines. These benefits of cellular manufacturing with respect to learning capability are mainly supported through the single phasing and repetition of the PBC system.

Delivery response

Cellular manufacturing systems often expect benefits with respect to smaller throughput times, higher dependability, lower work in progress, increased inventory turnover rates, smaller material handling costs, and so on. Olorunniwo and Udo (1999) even showed that these benefits contribute more to the success of cellular manufacturing systems than changes in the field of reward structures and change project management. The delivery response benefits that we mentioned are strongly interrelated, and they can only be achieved through modifications in the production planning system. Work should be released with shorter planned throughput times, changes should be made in the order release frequency, in the quality of scheduling within cells, and in the co-ordination of the transfer of material between successive stages. The three principles of PBC are directly oriented towards such changes. However, it depends on the specific design of the PBC system if these benefits of a cellular manufacturing system can be obtained fully by using a PBC planning system. This leads us to the argument that the PBC system supports the transparency needed to effectively exploit the advantages of a cellular organized manufacturing system. However, we consider PBC not to be a prerequisite for successful application of cellular manufacturing. Obtaining the desired benefits from cellular manufacturing will depend on the specific design of the PBC system.

§ 3.3 PBC planning system evolution

The three principles that are used in PBC systems seem useful in cellular manufacturing systems, as we have seen in the former section. However, the principles do not provide support for actual PBC system design choices in respect of the length of the cycle (offset)

time, and the number of stages. The evolution of the PBC system as reported in literature will provide us with insight in the historical development of thoughts on these important system design choices. This will help us to improve our understanding of this planning concept.

The changes into the field of production planning and production organization in the last decades have already been described in Chapter One. These changes have had their impact on the design of cyclical planning systems such as PBC. Literature on cyclical planning systems and, more specifically, on period batch control, gives us an impression of how these changes have been taken into account over time. In this section, we will trace these changes in literature with respect to the design of such a planning system.

§ 3.3.1 Single cycle ordering versus economic ordering

In 1960, Burbidge's first book on standard batch control appeared. This book describes his main objections to the use of economic batch quantities for the ordering of parts, which he considered to be pseudo-scientific nonsense in his first publication '*A new approach to production control*' (Burbidge, 1958). Economic ordering expects cost advantages from a trade-off between inventory holding costs and costs involved through reordering materials and fixing the order quantity at such an optimal predetermined level. Burbidge argues that the real cost advantages had to be sought in improving the material flow system and using balanced ordering of parts, based on explosion of end product demand. The economic ordering quantities do not take into account the variability of these cost factors, nor the costs of a lack of co-ordination in the system. These extra costs only become visible if product designs are changed, and the cost of irregular loading of the production system is considered. Measuring these costs is therefore not easy, and allocating these costs to planning decisions with respect to batch sizes seems less useful at the time of deciding about these batch sizes.

As an alternative to such an ordering system, Burbidge (1960) proposed always using the same small standard-sized batches for end products and ordering the required amount of parts and components. This standard batch control system only applies the principle of *single cycle ordering*, as the ordering of a small batch of end products is synchronized with the ordering of parts and components. The standard batch sizes are balanced according to the required amounts of a part in one end product. The standard batch control system is according to our definition *not single phase*⁶, as the moment of release of these orders depends on the consumption rate of the inventory of end products. As the rate of demand may vary, this

⁶ Note that Burbidge (1962) considers the standard batch control system to be single phase. He uses another definition than ours: '*Single phase ordering is a type of ordering in which all the parts made for a given product or assembly are ordered in balanced product sets, with the same ordering cycle (start and finish times), for all of them*' [1962: 456]. Later publications introduced terms which were not consistent with this one. The definition of Burbidge contains elements of our definition of a single cycle system at ordering level (*balanced product sets*), and of single offset time (*same cycle: start and finish times*).

causes a multi phase system. The standard batch control system is *neither necessarily single offset time*, as the (planned) throughput time of a work order for a standard batch varies per part and is not predetermined at all.

For the first time in 1962, a period batch control system was described in Burbidge’s book ‘*The principles of production control*’. Burbidge (1996) mentions that he obtained a letter from R.J. Gigli, who directed his attention to the possibility of standardizing the length of the order interval for all orders. He had described such a period batch control system in the *Material control reference book*, Associated Industrial Consultants, July 1947. The principles of period batch control originated from his work as a consultant, when he was director of Associated Industrial Consultants Ltd. in 1926. Gigli has also been working at the British ministry of aircraft production, where he was responsible for the design and application of a period batch control system for regulating the Spitfire production during World War II. Some of his applications were based on short term programs with period lengths of one week, others on four week periods. We have not been able to study the referenced work of Gigli. From Burbidge (1996) we understand that the principal ideas of Gigli’s system at that time were:

- to order periodically
- balanced sets of parts for aeroplanes, in order to obtain
- high stock turnover rates

Gigli introduced the name Period Batch Control. Burbidge further elaborated this planning concept and propagated its use in combination with Group Technology.

§ 3.3.2 Single cycle, single phase, single offset time planning

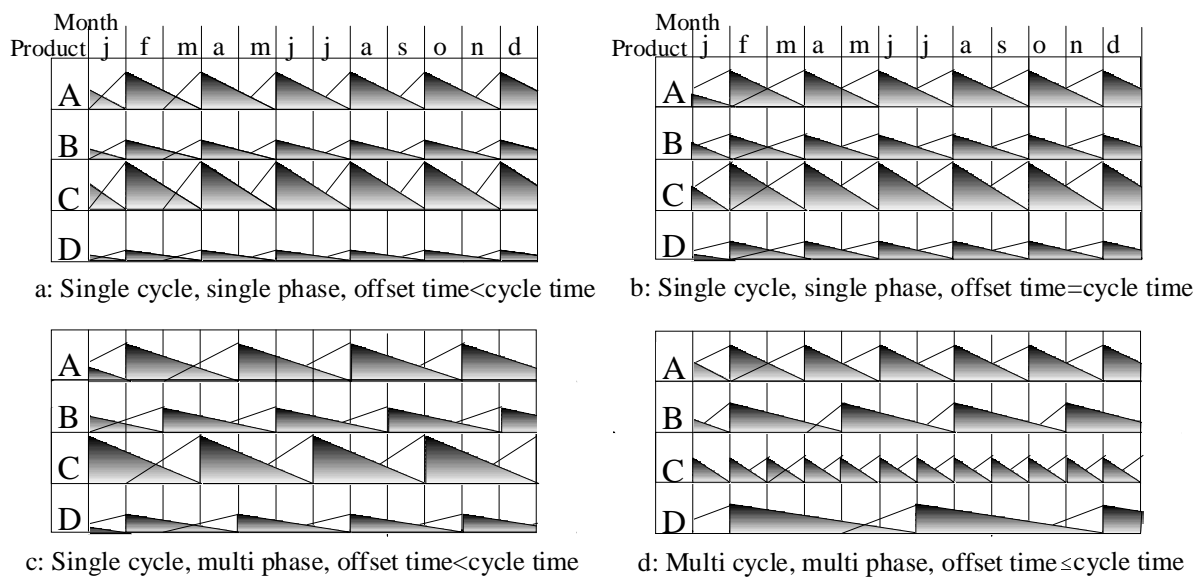


Figure 3.11 Cycle, Phase, and Offset time (a,c,d according to Burbidge [1962, fig 33])

There are some remarkable aspects of the description of period batch control that he gave in the 1962 book. The introduction of the concepts of single cycle and single phase in Burbidge [1962, figure 33] is shown in Figure 3.11. Figure a shows his interpretation of a single cycle/single phase system with a production period (offset time) of one month and a consumption period (cycle time) of two months. The quantity that is produced of each part differs, but all parts are produced during the same month. The difference with the single cycle / multi phase system in Figure c is the varying start and finish moment of the parts in the latter case. Note that Figure c obviously results in a better loading of the system than the single cycle / single phase system in Figure a. Figure d shows a multi cycle / multi phase system, and finally we have included Figure b, our definition of a basic unicycle PBC system that is single cycle, single phase, and single offset time. We already discussed this figure in Section § 3.1.

Burbidge divides the year into periods, e.g., calendar months. The required production quantities in a period are determined for each end product. A manufacturing throughput time of two times the period length is used. Burbidge denotes this manufacturing throughput time as the standard ordering schedule. Figure 3.12 presents the essential features of the system. From the accompanying explanation in his book, we know that the first month of the throughput time is used for producing part requirements. These parts are all released at the start of this month and are assumed ready at the end of the first month, but their progress is not explicitly monitored through PBC. Next month, the end products are assembled. We see that Burbidge introduces the single cycle system characteristic at ordering level that is essential for PBC, and also, but less explicit, the single offset time and single phase principles. Customer lead time includes the delivery to the customer.

| Assembly programme | | | | | | | | | Year: 1957 | | | |
|--------------------|-----|-----|-----|-----|-----|------|------|-----|------------|-----|-----|-----|
| | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
| Product A | 30 | 30 | 30 | | | | | | | | 30 | 27 |
| Product B | | | | 26 | 28 | 28 | 28 | 16 | 28 | 28 | | |
| Product C | 12 | 12 | | | | | 12 | 7 | | | | |
| Product D | | | 16 | 14 | | | | | | | | |
| Product E | | | | | | | | | 16 | 16 | | |
| Product F | | | | | 35 | 35 | | | | | 35 | 30 |
| Total | 42 | 42 | 46 | 40 | 63 | 63 | 40 | 23 | 44 | 44 | 65 | 62 |

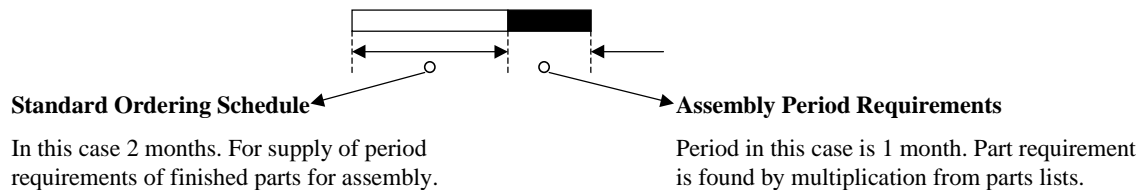


Figure 3.12 Essential features of period batch control (Burbidge, 1962)

If we compare PBC with the standard batch control system that Burbidge proposed in 1960, we see that PBC requires more calculations. The standard period length of PBC makes it necessary to determine each period the exact balanced ordering requirements based on the explosion of the parts lists. With standard batch control, these calculations had to be made only once if the batch size for an end product was determined. With PBC, the production quantity for each period is determined in the assembly program and may vary per period, as shown in Figure 3.12. There is no cyclic repeating occurrence of requirements for each end product in the assembly program. This illustrates that the PBC system description of Burbidge (1962) is a system that is *not unicycle*, as it is *not single cycle at programming level*.

§ 3.3.3 PBC system design

The description of period batch control shows that in 1962 his attention was directed towards the design of a system that could be used in co-operation with other systems, such as statistical inventory control. The system description is single cycle at ordering level, but not at programming level. Such systems face loading problems. This necessitated Burbidge to pay attention to the design of an adequate capacity control function at programming level. He also proposed to make some parts or products to stock in order to balance loads in the system and allow short throughput times. Burbidge (1962) proposed the following set of decisions for PBC system design:

- 1 The product units that are used for planning purposes in the assembly program.
These units need not be final products that are sold to a customer. The unit definition serves a planning purpose. The positioning of the CODP (Customer Order Decoupling Point) may lead to the situation that final assembly of the product units into a product for the customer is performed during the sales period, making it more appropriate to use non-finished product entities as planning units in the assembly program.
- 2 P: Period length determination:
Burbidge proposes to use calendar months or four-week periods. Any other equal division of the year can serve, as long as stock turnover rates are acceptable and the division is convenient for accounting purposes.
- 3 Selection of parts to be excluded from control with PBC:
 - Parts with very long lead times, so that they do not influence the length of the general supply schedule.
 - Parts that require higher turn over rates (expensive or bulky items).
 - Low valued units with even consumption rate, which can be controlled safely at a lower cost with stock control methods.
 - Common parts that can be made to stock in order to reduce the total throughput time.
- 4 Selection of processes to be excluded in the ordering schedule.
- 5 T Selection of the length of the ordering schedule (i.e., total throughput time T)
- 6 N Subdivision of the standard schedule into N stages:
Burbidge [1962: 293] notes that if items pass through a number of different production departments *'it is necessary to divide the standard schedule into subdivisions, allowing a set time, for example, for obtaining purchase deliveries, or for moulding in the foundry, and the remainder of the standard schedule time for machining. For simplicity this division is normally made on some arbitrary basis so that all castings, or all purchased special materials for example, fall due on the same date. This means that the foundry as well as the machine shop will both have set target dates on which to complete all their work on a batch.'*

The decisions pay attention to the division of the standard schedule into several stages, but it is not explicit on when and how to determine such divisions, and what consequences this will have on the capacity utilization in these parts of the production system. The ideas on the stage decomposition stem mainly from the description of the related standard batch control system in the same book.

Finally, although Burbidge (1962) pays in this publication much attention to production characteristics (mass production, line, batch, jobbing, contracting) and layouts (functional, group, and line layout), he does not consider group organisation to be a prerequisite for PBC. The opinion seems to be that whatever organizational division is applied, the design of PBC has to be such that it gives the required support.

§ 3.3.4 Group Technology and PBC

In 1971, Burbidge's view has changed with respect to the appropriate control system for batch production. Burbidge [1971: 405-406] argues that

- a single cycle ordering system with a short cycle and a standard machine loading sequence is a prerequisite for successful control with group technology⁷ and
- such a planning system can only be completely successful if group technology is used

His reasoning is mainly based on the idea that modifications are required in both the controlled system and the control system simultaneously. These modifications have to be in line. The design of the total system has to be reconsidered in order to find real improvements. Therefore (notwithstanding the somewhat doubtful quality of reasoning that Burbidge uses for the strong statements), we consider this to be an important step in the design of PBC systems.

The change in Burbidge's thinking about the applicability of cyclical planning systems in batch production may well be influenced by the work of a group of Russian researchers in the 1960s that became available in English in 1966 (Mitranov, 1959) and 1968 (both Ivanov and Petrov). Ivanov and Mitranov have contributed to the study of required modifications in production systems in order to enable production in groups, such as application of classification and coding schemes, and design of tools to reduce set-up times.

Petrov (1966) was one of the firsts who contributed to the thinking on redesign of the planning system when group production was applied. He performed research in 81 metal ware firms in the St Petersburg that had adopted group technology production principles. These firms used 137 flow line cells and had installed these groups following the central economic plan of the Russian government for the period 1963-1965, which ordered that more use should be made of group production structures. Petrov concluded that *'in the vast majority of group flow lines in operation, production is very far from being rhythmic, parallel or proportional, and the problems of materials and technical supplies have not been solved correctly. Basically this arises from the lack of co-ordination between production engineering aspects of flow line design and its organizational and planning aspects. ... The real saving to be achieved by adopting group techniques is for most part determined by the success or failure of the system of production organization and planning.'* (Petrov [1968: 9, 13]).

Petrov suggests several principles that should be followed when designing an appropriate planning system for group production. He proposes to take as starting point for planning system design the characteristics of the group structure in terms of specialization, required co-ordination, and internal structure. Next, he reconsiders the applicability or suitability of a

⁷ Burbidge (1971) defines *group technology* as the total of measures to be considered in order to make batch production profitable when using the particular basic solution of group layout. These measures could either try to simplify the material flow system, centralize responsibility for components, reduce set-up times, or reduce throughput times.

group structure in the specific situation with respect to the expected loading of the groups over time. This loading should be sufficient, both on the short and long term, in order to be able to load the various workplaces in the groups evenly. If this can be guaranteed, the following principles should be used when designing a planning system for group production:

- Principle of *synchronization*: the completion of one stage in production and the initiation of the next should be co-ordinated and synchronized. This generates a rhythmic production.
- Principle of *proportionality*: batch sizes or run frequencies of components should be either the same or a multiple of the one used for the products that require these components. Proportionality should be maintained throughout every stage and operation of the production process.
- Principle of *limitation*: the number of different ordering cycles in the system should be limited as far as economically can be justified.
- Principle of *cost balance*: the costs of operating the planning system should be balanced with the cost of operating the production system. Not only strive for rhythmic production and minimum cycle time, but also minimal set-up time and maximum batch sizes to obtain high productivity and low labour costs.
- Principle of *loading stability*: the loading of the groups, shops, sections, and work places, should be stabilized through a correct distribution of the total load over successive time intervals in order to generate a steady output.

The five principles of Petrov direct attention to the advantages of cyclical planning within group production. The particularities of this mode of production place other demands on the design of planning systems. The usage of these principles may help to improve planning for group production, but the set of principles is in itself not consistent. However, PBC system design in Burbidge (1971) did benefit from this description, amongst others with respect to the design of the standard ordering schedule and its subdivision through production flow analysis. The synchronization principle resulted in a more strict phasing of the stages that were distinguished.

§ 3.3.5 Stable loading and single cycle programming

The work of Petrov also provides insight in an important facet of group production, namely the increased sensitivity for loading imbalances. This imbalance can sometimes be tackled by the increased multi functionality within a group, but the loss of pooling synergy, as described by Suresh and Meredith (1994), remains a problem that has to be taken into account when designing a production planning system for group production.

Petrov's cyclical planning system was not single cycle at programming level, resulting in a surge effect as described in Figure 3.3. Descriptions of other cyclical planning systems, applied during the 1960s in Dutch companies such as Philips (see e.g. Botter [1967:chapter 7])

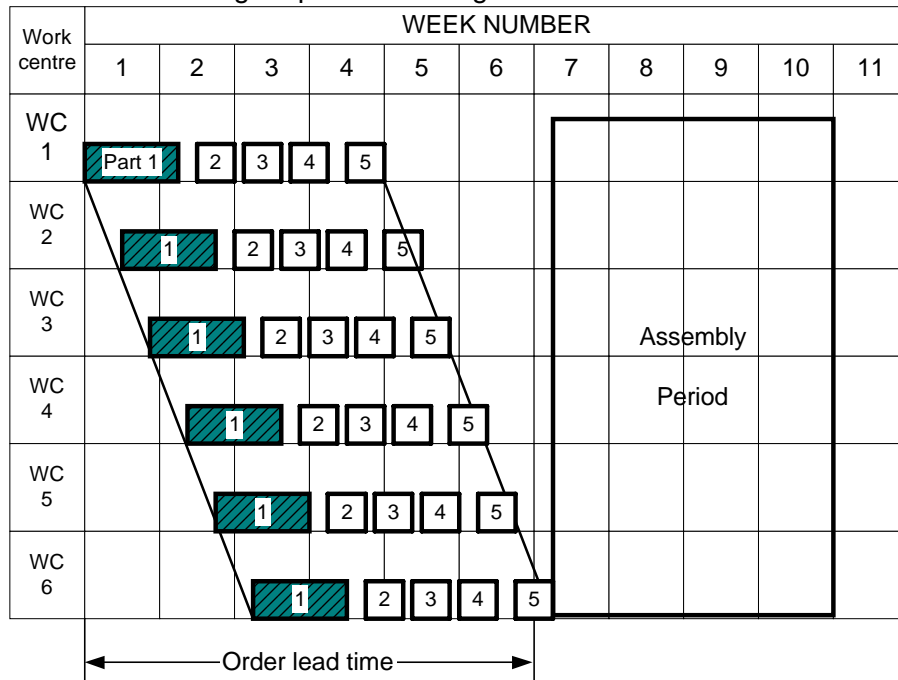
and Ham [1969:chapter 5,6]), give the same impression. The systems described in these publications use a fixed period between the issuing of new orders for a type of product, mainly to improve the detailed production planning. However, the cyclical systems in the Netherlands operated with rather long cycles and faced a number of fundamental problems, such as many disturbances, many urgent orders, high inventories, long throughput times, and a low lead time dependability (Monhemius, 1989). Improvements for these systems were sought in the development of more advanced statistical inventory controlled systems instead of searching for improvements in the fit between the controlled system and the design of the control system. The organization of the production system itself became no subject of study, and many of the researchers were more fascinated by the increased possibilities of applying computers and operations research techniques, a trend which we have described already in Chapter One.

In England, the development of cyclical production planning systems did continue with the work of Burbidge (1975a) and New (1977). Here, the attention also focussed on the advantages of finding optimum loading schedules for groups in case of repeating patterns. However, they concluded that these repeating patterns would more often occur if the planning system would become single cycle at programming level as well. If each product would be ordered each cycle, the loading of the system would only depend on the variety in the volumes required per period, not on the amount of set-up time needed. The planning and preparation of the set-ups could be performed in advance such that high learning effects could be achieved. Set-up times were therefore not considered to be fixed, but could be influenced by the cyclical planning system. The same would hold true for the utilization of raw material. They believed that grouping of work orders requiring the same input material for their first operation would introduce new batching possibilities. Economies of scale would therefore still be achievable.

Burbidge (1975a) noted that in a single offset time, single cycle system at programming level, loading is easier to accomplish, because of the direct relationship between actual capacity requirements and production periods. Regulation of capacity through overtime working or outsourcing may still be required and is decided upon within the program meeting. The possibility of a transfer of work men between groups is considered only in severe cases. PBC requires additional control mechanisms for correcting stock positions due to higher or lower yields than expected, or to errors in the scrap and spares forecasts [1975a: 95]. This also leads to possibilities for regulating capacity requirements.

In order to develop optimum loading schedules for the single cycle system at programming level, standard sequences were proposed. Burbidge calls this cyclic planning, and the figure that he uses is presented in Figure 3.13. He describes a flow shop (each work order may have different processing times, but requires processing in the same sequence at all work centres). The loading sequence that he applies is a permutation schedule. Note that a permutation schedule need not be optimal with respect to make span minimization in case of a flow shop with more than three machines.

A standard loading sequence is designed



This standard sequence is repeated every cycle

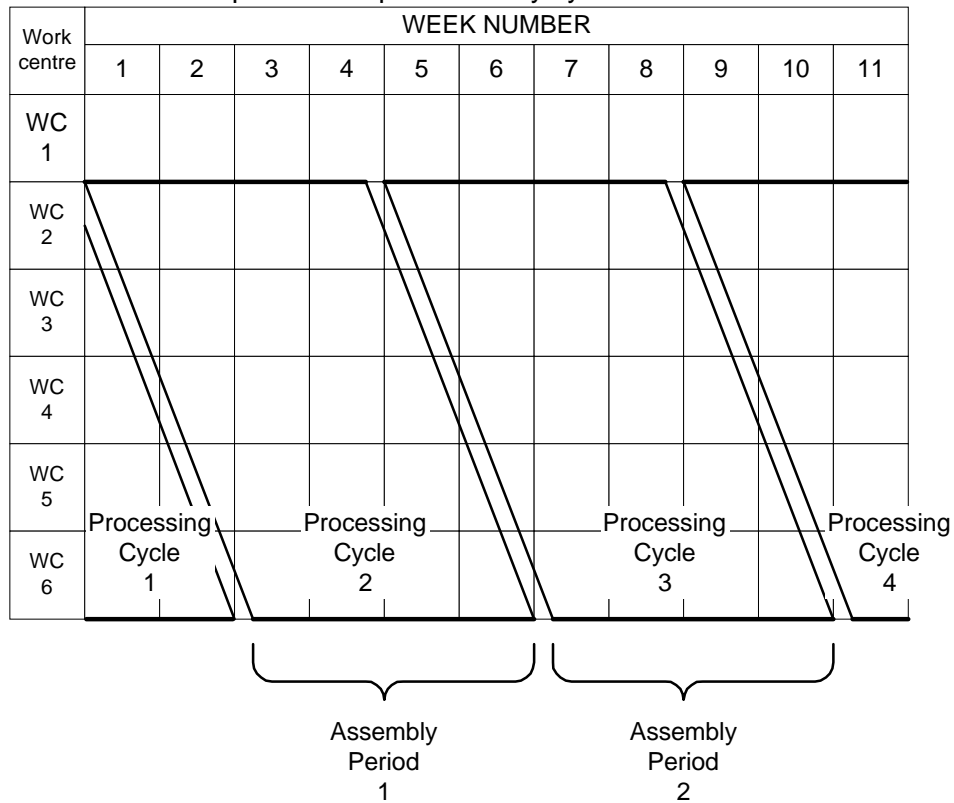


Figure 3.13 Cyclic planning according to Burbidge [1975a: figure 3.6]

§ 3.3.6 Overlapping production and multi phase cyclical planning

The loading sequence as presented in Figure 3.13 shows that the next work centre already starts with a work order while the same order is being processed at an earlier work centre. This is the first time overlapping production, or *close-scheduling* (the term used in PBC literature), is being introduced in the description of a cyclical planning system. The organizational impact of such a measure is quite high, so it can only be applied if the successive work stations are able to co-operate in the quick processing of the complete work order. Both the application of a group layout and the learning effect that leads to a reduction in throughput time facilitate the successful application of overlapping production for at least some critical components.

Another remarkable aspect of Figure 3.13 is the parallelogram that arises in the processing cycle. This parallelogram implies that each *work centre* operates with a cycle length of four weeks (a single cycle, single offset time system for work centres), but the order lead time in the processing *stage* is six weeks instead of four weeks. It is therefore not a single cycle, single offset time system for the co-ordination of successive stages. The assembly stage starts in week seven, which probably means that all five work orders have to be ready before assembly can start. Assembly takes four weeks; it is depicted as a rectangle instead of a parallelogram.

The cyclical system that is described is not a single phase system. Each work centre receives the work of a cycle on another moment in time, but obtains a full cycle of four weeks to finish this work. The cyclical planning system operates therefore without a fixed synchronization moment or mechanism. The decision space of a work centre is very restricted in such a multi phase cyclical planning. It is not possible to change the sequence of work order processing without negative consequences for the make span of the whole set of work orders at the last station, as long as the loading of the system is as high as shown.

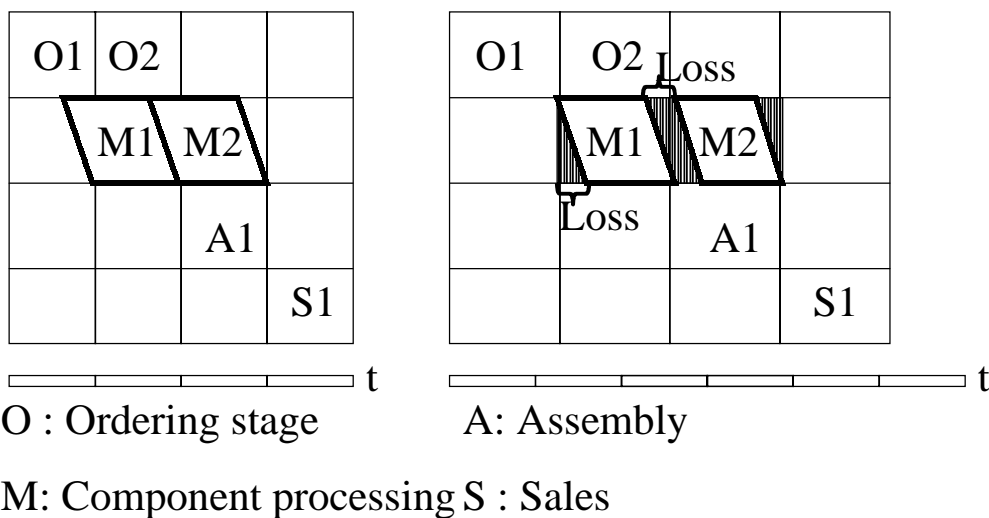


Figure 3.14 Flow shop cyclical planning

Burbidge [1975a: 81] describes that there are in general two possibilities for the problem of flow shop processing in the component processing stage. These are depicted in Figure 3.14. The left figure shows the same pattern as in Figure 3.13. During the ordering stage O1, processing already starts in M1. Ordering of the parts required at the first machines has to be speeded up, as less than the available period length is available for ordering. This solution cannot easily be applied in case of a (sub)assembly stage, as the availability of all materials is required at the start of this processing step.

The alternative is depicted at the right side in Figure 3.14. The period length has been increased, in order to be able to complete the whole set of work orders within one period. This has led to an increase in the throughput time as well as in the volumes to produce each period. The losses are accepted as an allowance for late work and to provide capacity for rush orders and other additional work, as Burbidge notes.

§ 3.3.7 Information technology and PBC

The contribution of Collin New (1977) to the thinking on cyclical planning systems has been important. First, he discusses the changes imposed in PBC planning system design by the possibilities of computerized support. He considers the argument of designing a system with as simple calculations as possible no longer to be valid. The introduction of the computer makes it easier to design tailor made planning systems where specific product types are treated differently within the same system concept. Parts with extremely long or short throughput times, expensive items, and items that are produced with uncertain yield, and so on, can more easily be controlled by the application of specific planning principles.

Notwithstanding the above, New favours the application of single cycle systems, particularly period batch control, when coupled with group production. The administrative tasks with respect to the bills of materials, and the determination of parts requirements (explosion and allowance calculations) should be provided by computers, but the role of the computer in actually controlling work order progress would still be marginal. With group production, the information requirements on actual work order progress would be lower compared with functional organized production. Therefore, group production supports a more appropriate distribution of computerized planning tasks and human planning tasks. The PBC system that New proposes is a unicycle period batch control: single phase across all products, and single cycle at *both* programming *and* ordering level. This single cycle causes a repeating pattern in the loading of the groups, which enables them to determine a planned loading sequence of the various machines, possibly with the aid of a computer. This re-usable planned loading sequence might include overlapping machine operations and planned usage of family set-ups.

New suggested to integrate the strengths of group organization, cyclic planning, and control procedures from material requirements planning systems in order to contribute to the improvement of component production. His introduction of the unicycle PBC concept is

important in the development of thinking on cyclical planning systems. His reasoning on the combination of computer power, cyclical planning, organizational decomposition, and allocation of responsibilities and planning tasks, is more precise than the one offered by Burbidge. However, he does not really contribute to an appropriate design of a PBC system. Stage definition, raw material achievement, and period length setting are not treated in depth.

Suresh (1979) describes the applicability of New's ideas for an automobile ancillary industry firm in India. The firm used to produce components in a monthly cycle. A successful introduction of a MRP system should take into account the possibilities of using group production and simplifying the production control system. Group production would enable the firm to produce with much smaller and predictable lead times. A cyclical planning system would reduce throughput time and simplify loading decisions. The basic requirements of a computerized planning system, like the proper structuring of the Bill Of Material, realism of the master schedule, and accuracy of the inventory records, would remain unchanged as compared with a direct introduction of an MRP system. From a systems engineering point of view, a PBC system could be introduced using standard available MRP software. The 'parameterisation' of this software would either or not make it a unicycle PBC system.

Burbidge (1979) fears that using a computer in order to centrally determine schedules for coordinating the flow within the groups results in undesirable effects. This task can better be performed within the cell, as relevant information is available at this level, and the effect of measures can be seen directly. Information at central level is often less accurate, less precise, and less timely available. If the opportunity to plan and control the work within the cell is given to the cell, this often increases workers job satisfaction. He does not discuss the setting of PBC system design parameters in order to make these decision processes more effective.

Hyer and Wemmerlöv (1982) are very critical on the applicability of cyclical planning systems for cellular manufacturing. They formulate five points of criticism. In their opinion, (1) the sensitivity of a cyclical planning system for demand fluctuations is too high, causing the system to suffer from unacceptable over- or under-capacity utilization. They assume that the low level of sophistication in the usage and understanding of computerized planning systems in British industry has led to the propagation of using simplistic production planning procedures that are only attractive in combination with cellular manufacturing.

They state that one of the drawbacks of using PBC in connection with manufacturing cells is (2) the absence of clear guidelines for determining the correct cycle length. Furthermore (3), they think that, regardless of the specific cycle length, there may exist an inherent capacity imbalance between component production and assembly, as both processes need not require the same cycle time to produce the required products for a specific cycle. Note that the latter comment is clearly a misconception with respect to stage definition within PBC, which allows more stages for component production if required.

Wemmerlöv and Hyer are very critical on (4) the applicability of planned loading sequences. They argue that literature on PBC has not proposed specific methods for generating such sequences, neither has it considered the consequences of mix variety or lumpy demand for these sequences. Only if the cycle length becomes sufficiently small, such as in Japanese production planning systems for cellular manufacturing, the PBC cyclical planning system comes close enough to these systems and may become appropriate for cellular manufacturing.

Finally (5), the problem remains on the use of two planning systems simultaneously, one for the cellularized part of the firm (PBC) and one for the non-cellular part of the firm (traditional MRP). They refer to their experience, which had shown that firms did only allow minor changes in the production planning system when changing towards cellular manufacturing.

The work of Hyer and Wemmerlöv (1982) has had a strong impact on later research on planning for cellular manufacturing in the United States, considering the number of citations it received. However, two years later another influential publication on cyclical planning systems occurred from Whybark (1984), one of the leading researchers in the USA on MRP system design. We already discussed his system for the Finnish Kumera Oy in Section § 3.1.4 and Figure 3.6. Whybark found an increase in inventory turnover, delivery accuracy, and margins. The factors that counted for these benefits were: a simple planning system, easy to implement, easy to work with, and easy to improve according to suggestions of the users. He views the cyclical schedule as a train schedule⁸. He directed the attention in planning system design not only towards accurate information and planning tools, but also to accurate order acceptance and co-ordination between production, sales, engineering, and management.

The renewed insights on cyclical planning systems were included in Wemmerlöv (1988), an APICS book on '*Production planning and control procedures for cellular manufacturing*'. This publication gave a less pessimistic and more accurate impression of the strengths and weaknesses of the applicability of cyclical planning systems in cellular manufacturing. Wemmerlöv favoured the cyclical system that was applied by Whybark over the more rigid basic unicycle PBC system. His argument was, that PBC omits an instrument for co-ordination within or between cycles with respect to the sequence, while the use of these planned sequences seemed him to be a major justification for the use of PBC in cellular manufacturing. We think this is not a valid argument for favouring Whybark's system over PBC. First, the sequencing problem within a cycle in the Finnish system is more problematic than in standard PBC, due to the multi phase system that was introduced and the absence of a synchronization mechanism between the release moments. Second, sequencing between cycles is adequately performed through the synchronization mechanism of PBC. Whybark's system uses the same mechanism between parts production and assembly.

⁸ Apparently this metaphor presumes a well operated train system, in which trains that have departed do not return for late passengers, and do ride according to their time schedule.

With respect to the simultaneous use of PBC in combination with other systems, such as MRP and Kanban, Wemmerlöv (1988) noted that PBC could be combined with a pull system such as Kanban for order execution. The use of PBC for companies with an MRP would make it necessary to change mainly the way of working instead of change the type of computer support system. Wemmerlöv therefore recognizes that the benefits of a cyclical planning system, based on repetitiveness and constancy, can be achieved through the combined usage of elements of PBC, MRP and Kanban.

Burbidge (1988) pays attention to the consequence of the occurrence of bottlenecks within the cells for PBC systems. The OPT system of Goldratt (1980) seemed to be an alternative for a cyclical planning system such as PBC. In case of bottlenecks in cells, the loading sequence within these cells becomes very important, as cyclical planning system require that all work has to be finished at the end of the period. If other machines have to be visited before the bottleneck can start processing, this incurs even some start losses for the bottleneck. The same holds true at the end of the period (finish losses). Burbidge suggests that this situation can be handled within PBC by appropriate scheduling of the first and last activities, and of the bottleneck activities. For this purpose, specific tools should be made available within cells.

Burbidge does not criticize the bottleneck scheduling method of OPT, but the overall planning method is not copied into the PBC framework. He suggests to use OPT for determining planned loading sequences at the bottleneck. We consider this to be a misconception of Burbidge with respect to the significant consequences of using the OPT scheduling method for preceding and following processes. Further, note that Burbidge does not try to decouple the bottleneck process from other processes in the cell or system. He leaves the definition of a work order and the cyclical character of the planning system unchanged if bottlenecks appear.

§ 3.3.8 Cyclical planning to improve rather than just co-ordinate production

Hall (1988) considers the application of cyclic schedules as a major step in actually achieving both improvements in manufacturing organization and close synchronization. His publication positions cyclic scheduling as a vital concept in the framework of continuous improvement. The contributions expected from cyclic scheduling systems are amongst others:

- improved supply chain co-ordination
- elimination of causes of disturbances instead of reacting to disturbances
- improved introduction of engineering changes on effective dates that correspond with the predetermined release moments of work orders
- increased consciousness of internal client/server relationship between successive cycles

In order to develop repetitive manufacturing, Hall states that the cyclic schedule and the transformation process must be developed symbiotically. Furthermore, both will evolve over time. This will have consequences for the length of the schedule period. Shorter scheduling periods result in more required flexibility, due to short term variations in customer demand.

Hall notes that the length of production cycles should not be determined based on preferred cycles of internal accounting reports, or sales departments. The production system improvements can only be found if the cycle length is determined with respect to the supply chain characteristics, both internal and external of the firm.

Halls's cyclic scheduling system is not particularly a PBC system. Many of the ideas stem from the Japanese systems that apply multi phase, very short but multi cycle systems. Still, the notion that cyclical planning systems help to improve the transformation process instead of simply co-ordinate these processes meant an important step in the development of thinking on cyclical planning systems. This notion differs from the line of thinking on MRP system effectiveness, that evolved in terms of data accuracy, system reliability, and degree of actual usage, resulting in classifications of users as class A, B, C, D firms, see e.g., Wight (1984).

The renewed interest in cyclical planning systems, both in industry and research community, resulted in theoretical progress and combination of insights from several branches of research. Methods that were developed for multi item lot sizing, capacity constraint scheduling, sequencing, and synchronized flow production were partly integrated. Luss (1989) showed that the smaller the length of the production interval in the first stage, the more effective the synchronization in the system. Shtub (1990) argues against the assumption of PBC that discrete demand lot sizing policies are not cost effective in cyclical planning systems. He develops a heuristic lot sizing procedure based on the traditional trade-off between set-up costs and inventory costs. His work received attention of Jamshidi and Brown (1993) and Rachamadugu and Tu (1997), who continued the research on other lot sizing approaches within a PBC framework. They do not use a single cycle ordering approach for all products and parts in the system, but search for common cycles for *subsets* of parts and products.

Other research on cyclical schedules, such as Loerch & Muckstadt, 1994, and Ouenniche & Boctor, 1998, direct attention to the determination of suitable production cycles in combination with appropriate (powered nested) batching policies. From a theoretical point of view, their work attempts to fill the gap that was earlier identified with respect to the planning and sequencing problem within cyclical systems such as period batch control systems.

In Germany, Habich (1990) examined the consequences of the introduction of group production for work order release and the type of planning within and between groups. He concludes that the design of the co-ordination between the autonomous production groups is essential for obtaining the desired benefits of group production. A cyclical operating co-ordination system enables an increase in flexibility and autonomy of the groups. Cyclical planning systems provide transparency and enable the development of appropriate planning tools for specific groups. Such tools may help to estimate required capacity, or to represent work order routings within the group graphically. The characteristics of autonomous groups and their coexistence within one production system results in the specification of requirements for the planning system. Co-ordination improves if the decision moments on work order release are in phase.

§ 3.3.9 PBC, MRP and Kanban

At the end of the 1980s, a number of papers appeared that compared the performance of MRP systems and several variants of it with Kanban. The relationship between this performance and the manufacturing organization was being studied (e.g., Schonberger, 1983, Krajewski, King, Ritzman, & Wong, 1987). Wijngaard (1986) propagated the need for a contingency approach in finding appropriate methods of planning for specific situations. A contingency approach ascertains the strengths and weaknesses of each system. This redirected attention towards the properties of the PBC system. Many of the publications had favoured Kanban systems for the low inventories and short throughput times, but the period batch control system was said to achieve the same performance if combined with group production. Therefore, PBC received renewed attention from the research community as a consequence of the broad interest in cellular manufacturing in western industry and the conquest for finding production and market characteristics that favour particular planning and control approaches.

A number of papers appeared that compared PBC with MRP and Kanban, e.g., Yang & Jacobs, 1992, Kaku & Krajewski, 1995, and Steele, Berry, & Chapman, 1995. The results of these comparisons were contradictory. Yang and Jacobs found that the order release and due date assignment procedure of MRP always outperformed the rigid PBC system. Steele et al. found on the contrary that PBC systems outperform MRP and Kanban systems under specific circumstances with respect to set-up times and variation in the order mix. The contradiction in research outcomes showed that the decisions on the specific design of the systems that were compared and the inherent assumptions that were made in building the simulation models first had to be made explicit and studied on their own. Former studies often selected PBC design parameters for similarity with MRP or Kanban practice.

Rees, Huang and Taylor (1989) already had paid attention to the design of the systems they compared. They studied the possibilities to achieve the same cycle times within an MRP system by applying lot for lot batching (L4L, i.e., single cycle at ordering level). They did not introduce a single offset time in their MRP L4L system, which distinguishes it from the basic unicycle PBC system. The performance of Kanban was compared with MRP L4L if both were operating under almost equal conditions, with identical short cycle times. The simulation results showed that the cyclical operating MRP L4L system generated greater savings than the Kanban system, in spite of the fact that some MRP offset times were longer than the Kanban throughput time. If MRP and Kanban were both implemented at the same number of cycles per day, the results favoured MRP L4L because it required fewer set-ups *and* less inventory.

The research of Rees, Huang and Taylor (1989), and the contradictory result of the comparisons of several systems renewed the interest in an appropriate design of cyclical planning systems as PBC. Wemmerlöv (1979) already had pointed towards some important design factors of MRP systems. He concluded that the selection of the time bucket length, offset times, cycle times, and the structuring of the bill of materials could help to improve overall system performance.

Steele and Malhotra (1994, 1997) provided an important contribution to the identification of PBC system design factors. The design factors that they proposed were: period size and transfer batch size. They asserted that MPS load variation and capacity imbalance would have important influence on the performance of a PBC system. The design of the PBC system should depend on the delivery performance of the weakest element in the chain. Furthermore, the PBC design would be affected by the possibility of adjusting capacity, and by the length of the customer order lead time that would be acceptable in the market.

The list of design factors of Steele and Malhotra (1994, 1997) is created under the assumption that the structure of the production system is known when designing a PBC system. They assume a direct relationship between cells and PBC stages and therefore use a constant number of stages. Finally, they assume an important effect of PBC system design choices on the capacity adjustment property of the planning system, but they do not identify the influence of the relationship between cellular structure and PBC system configuration on this system property. The conclusions on the sensitivity of PBC performance for several sources of variation may well be affected by the presumed strong connection between production system and planning system structure.

§ 3.3.10 Concluding remarks

The evolution of the PBC system reveals that the three principles single cycle, single phase and single offset time have gradually emerged. Many changes in the PBC system have been considered during the last decades. The causes for these changes are the same as described in Chapter One: advances in information technology, planning theory, changes in required internal or external performance, and so on. Cyclic planning systems such as PBC still receive attention for their transparency, improvement potential, and suitability to support flexibility and autonomy in cells. PBC has been compared with planning systems as MRP and Kanban.

The contradictory results of the comparative simulation studies have shown that the *design* of the PBC system is an important determinant for performance improvement. Design problems that have been studied are the relationship between period length and batching policy, the relationship between production and planning system structure, and the development of capacity adjustment policies. However, these studies assume certain characteristics of the PBC system without considering the issue of determining appropriate values for the design factors in PBC system design. A too restricted view on PBC performance and possibilities results. Therefore, the problem of how PBC design choices affect performance and how this performance is influenced by several sources of variation remains poorly understood.

§ 3.4 Outline of research on Period Batch Control system design

The design of a PBC system requires careful examination. Our critical examination of studies on PBC system design and the design factors that were proposed in literature brings us to the main question of the remaining part of this study:

*What choices have to be made
when designing a basic unicycle Period Batch Control system
for the co-ordination between cells
and how do they affect performance?*

Chapter One and Two have described some general factors for planning system design for cellular manufacturing. In order to obtain an effective period batch control planning system, we have to identify additional factors that relate to the essential characteristics of the PBC system itself. Section § 3.3 has shown that the contribution of several important aspects of planning system design, such as the period length, bill of material structuring, and the use of transfer batches (overlapping production), is often studied independently from other aspects of the design of production systems.

The purpose of the remaining part of our research project is to improve our understanding of the relationship between production system design choices (the specificity's of the cellular manufacturing system) and PBC planning system design choices. We want to identify and analyse the contribution of the various design factors on the effectiveness of a basic unicycle PBC system.

Chapter Four will identify the main factors that have to be taken into account when designing a basic unicycle period batch control system. It studies the interrelationship between factors in both production and planning systems and their influence on system performance. Finally, it discusses the determination of suitable values for PBC design parameters, such as the period length P , the number of stages, and the definition of stage decoupling points.

In Chapter Five, we will pay attention to the development of methods to determine the period length in combination with the use of planned loading sequences. We develop mathematical methods that support the determination of suitable values for the period length and the number of transfer batches in the system, and we show the effect of varying either of these parameters. In this chapter, we consider the number of stages to be a result of the choice of period length and the batching policy applied.

Literature on PBC stresses the importance of determining PBC system parameters in order to reduce the manufacturing throughput time. In Chapter Six, we test the influence on system performance of varying both the number of stages N and the period length P for various batching policies while the manufacturing throughput time remains constant. The simulation

analysis that we apply examines the effect of varying these system design parameters on the amount of overtime work and costs for cellular production situations.

Chapter Seven studies the design process of a PBC system. The applicability of the methods that we developed in Chapter Five for determining a configuration for the PBC system is considered. We compare the performance of the proposed configurations with the configurations that we simulated in Chapter Six.

Chapter Eight considers the effect of different designs of a PBC system on the co-ordination requirements between cells in the cellular manufacturing system. These co-ordination requirements are related to the type of uncertainty. We examine the effect of PBC system design choices on the occurrence of this uncertainty within and between cells. The co-ordination that PBC provides may be insufficient if we encounter relationships between cells within a stage. We introduce the notion of stage co-ordination in order to fill this gap.

Finally, Chapter Nine presents the conclusions of this study and provides some recommendations for future research.

This study does not aim at presenting the basic unicycle PBC system as the major production planning system for cellular manufacturing. There are many situations in which other systems will be more appropriate. The rigidity of the PBC system that we examine is in most cases too strict to be of direct practical use. Developments in the field of information technology might enable firms to control the problems of planning system nervousness, loading imbalances, and lack of transparency of work progress alternatively and possibly more efficiently as compared to using a PBC system.

However, cyclical planning is still a very interesting approach, favoured in lots of work on production planning systems as shown above. It enables firms to focus their attention on system wide improvement of the co-ordination of their production system. Firms that apply such a planning system may benefit from the insights that are generated in this study to find a more appropriate design of their system. We view the PBC system as a stripped MRP planning system, as it uses equivalent co-ordination principles. It is a less rich approach, as it allows fewer decisions about system design parameters. This makes the applicability of PBC more restricted compared to MRP. However, the decisions that have to be taken in a PBC system are equally important in alternative planning systems. Therefore, studying the PBC system will be relevant for academic researchers that are involved in evaluating alternative planning system approaches as well. It will enable them to improve the design of proposed planning systems before attempting to compare their effectiveness with other systems.

